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Tribological Behaviour of Aa6061 Alloy Reinforced with Boron Carbide Particles at Room and Elevated Temperature

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Abstract: The present study deals with the fabrication of AA6061/boron carbide metal matrix composite and investigation on its tribological behaviour at room and elevated temperature. The composite incorporated with 0%, 1%, 2%, 3% and 4% of boron carbide was fabricated through liquid metallurgy route. The microstructure of this composite was examined and uniform distribution of reinforced particles in the matrix was observed. Wear experiments were conducted on Pin-on-disc tester at room and elevated temperature using process parameters such as applied load, sliding velocity, sliding distance, temperature; each varied for different levels. Minimum wear rate was observed for 4% B_4C. Worn surface were studied using Scanning Electron Microscope to understand the wear mechanism exhibited by composites prepared. It was observed that, severe delamination occurred as applied load increases. This tribological analysis can be utilized to replace the conventional aerospace, automotive materials with other aluminium metal matrix composites having better wear characteristics.
Keywords: AA6061, B_4C reinforced AMC's; dry sliding wear; elevated temperature, SEM analysis

I. INTRODUCTION

The modern development need of development of advanced engineering materials for various engineering application goes on increasing. To meets such demands composite material is one of the reliable solutions. Composite material is made by combining two or more materials to give a unique combination of properties. The metal matrix composites (MMCs) consists of at least two physically and chemically distinct phases, suitably distributed to obtain properties not obtainable with either of the individual phases [1, 2].

Aluminium metal matrix composites (AMCs) have captured the attention of material community to a large extent. AMCs possess greater strength, improved stiffness, reduced weight, improved high temperature properties, controlled thermal expansion coefficient, heat management, improved abrasion and wear resistance, excellent fatigue properties, high formability. Properties of AMCs can be tailored by varying the type, size of constituents and percentage of reinforcemt [3]. AMCs has become major focus in marine, automotive and aircraft industries due to their excellent properties. There are used particularly in the manufacturing of automotive components such as pistons, cylinder blocks, cylinder heads, cylinder liners, drive shafts, brake rotors, intake manifolds, rear axles, differential housings.

AA6061 is one of the most versatile and widely used alloys in numerous engineering application including construction and transportation where superior mechanical properties such as hardness, tensile strength etc., are essential required [4]. AA6061 has excellent corrosion resistance to atmospheric condition and good corrosion resistance to sea water. This alloy also offers good finishing characteristics and responds well to anodizing. Application range from machinery and transportation components to recreational products and consumer durables [2].

Boron carbide is a robust material having excelling chemical and thermal stability, and is the third hardest material after diamond and cubic boron nitride, which possesses low density (2.51 g/cm3), high hardness (HV 30 GPa), very high stiffness (445 GPa), high specific strength, high Elastic modulus, high refractoriness and toughness, higher bending strength, high shock resistance, high wear and impact resistance and is used for manufacturing armour tanks, bullet proof vests etc. [5, 6]. The high hardness of B_4C is attributed to the presence of B and C which forms covalently bonded solids. A limited research work has been reported on AMCs reinforced with B_4C due to poor wetting and high raw material cost.

Boron carbide (B_4C) particulate reinforced aluminium composites possess a unique combination of good wear resistance, high specific strength, high elastic modulus, and good thermal stability than the corresponding un-reinforced alloy. Hence B_4C reinforced aluminium matrix composite has gained more attention with low cost casting route [6].

The tribological behaviour at room and elevated temperatures of AMCs reinforced with B_4C have been widely studied. There are many reports on the effects of size, shape, orientation and volume fraction on the failure modus and fracture mechanism [7]. However, the literature reports the few data on effect of B_4C particles as reinforced AMCs at elevated temperatures. Thus, this work is aims to evaluate the effects of the temperature on tribological properties of AA6061 reinforced with B_4C particles [8].

II. EXPERIMENTAL PROCEDURE

Dry sliding wear tests were performed on B_4C particles reinforced AA6061 alloy matrix composite. Table 1 shows the nominal chemical composition of AA6061, and Table 2, shows the properties of B_4C. Boron carbide (B_4C) of particle size 220 mesh size is chosen as reinforcement material.

Table 1 Chemical composition of AA6061.

Elements	Mg	Si	Fe	Cu	Mn	Cr	Zn	Ti	Al
Wt. %	0.95	0.54	0.22	0.17	0.13	0.09	0.08	0.01	Bal.

Table 2 Properties of B_4C

Density	Hardness	Young's Modulus	Stiffness	Melting Point
2.52 g/cm^3	30 GPa	540 GPa	445 GPa	2880 °C

Metal matrix composites are generally produced either by Liquid Metallurgy Route (LMR) or Powder Metallurgy Technique (PMT). In the LMR the particulate phases are mechanically dispersed in the liquid phase before solidification of the melt. The proposed AMCs was produced by the liquid metallurgy route. To improve wettability between B_4C with Al matrix the K_2TiF_6 halide salt (Potassium titanium fluoride) is added as a flux to the melt. At an appropriate Ti level, the titanium rich reaction layer covers the B_4C particulates and thus these particles are wetted by Al melt. The titanium rich layer consists of particle clusters of titanium carbide and titanium di-boride formed on the B_4C surface. K_2TiF_6 incorporate B_4C particulates in the melt. Also, magnesium present in AA6061 alloy is also found to increase the wettability of the particulates by reducing the surface tension of the melt.

A batch of 250g of AA6061 was melted at 760 °C in a graphite crucible using an electric resistance furnace. The melt was agitated with the help of a zirconia coated steel rod to form a fine vortex. 3g of degassing tablet (C_2Cl_6-Solid hexachloro ethane) was added to the vortex and slag was removed from the molten metal. Degasser remove all the absorbed gases in the melt. Once the temperature reaches 810 °C the preheated mixture of B_4C (200 °C for 1 hour) with an equivalent amount of K_2TiF_6 halide salt (with 0.05 Ti/ B_4C ratio) were added at a constant feed rate of 0.5-1.0 g/s into the vortex with mechanical stirring at 300 rpm for 5 min. Before pouring the molten metal to the mould, 2g of cover flux (45% NaCl + 45% KCl + 10% NaF) was added to the molten melt to reduce atmospheric contamination. Cover flux helps in decreased contact angle and surface tension forces. The molten metal at a temperature of 860 °C was then poured into the graphite mould preheated to 300 °C after holding the melt for an interval of 1-2 minutes and allowed to solidify. The AMCs having particle size of 220 mesh with varying weight percentage of 0%, 1%, 2%, 3% and 4% of B_4C were fabricated by the same procedure.

III. WEAR TEST

The dry sliding wear tests were carried out according to AST - G99 standards using a Pin-on-Disc type wear testing machine (TR-20-PHM-400, DUCOM). The composite specimen of a pin were rubbed against a hardened steel at various load conditions such as 9.81 N, 19.62 N, 29.43 N, 39.24 N and 49.05 N; Sliding Speed of 0.94 m/s and sliding distance of 282.7 m; temperature of room, 50 °C, 100 °C and 150 °C. The pin was loaded against the disc through a dead weight loading system. The pin test sample dimensions were 10mm diameter and 30mm height. It is important to make sure that the test specimen end surfaces were flat and polished metallographically prior to the testing. The surface of the pin sample was rubber over emery paper of 80, 240, 320, 400, 600 grit size prior to the test to ensure effective contact of fresh and flat surface with the steel disc. The wear track and samples were cleaned with acetone and weighed using electronic balance before and after each test. The wear rates measured in weight units were then converted to volumetric wear rates. The microstructure investigation on the worn surface were performed by SEM.

IV RESULTS & DISCUSSION

A. Microstructure

The SEM mcrographs illustrates the microstructure of AA6061 composite with different volume fraction of B_4C shown in Fig.1. The SEM images reveal that the homogeneous distribution of B_4C particles in the aluminium matrix for all wt. %. This can be attributed to effective stirring action and use of appropriate process parameters during casting and also due to the equal value of density of matrix and reinforcement material causing the particle neither float nor descent in the mixture. The K_2TiF_6 flux has improved the wettability of B_4C particle with molten aluminium. The incorporation of B_4C particle in the aluminium matrix is facilitated by the K_2TiF_6 flux.

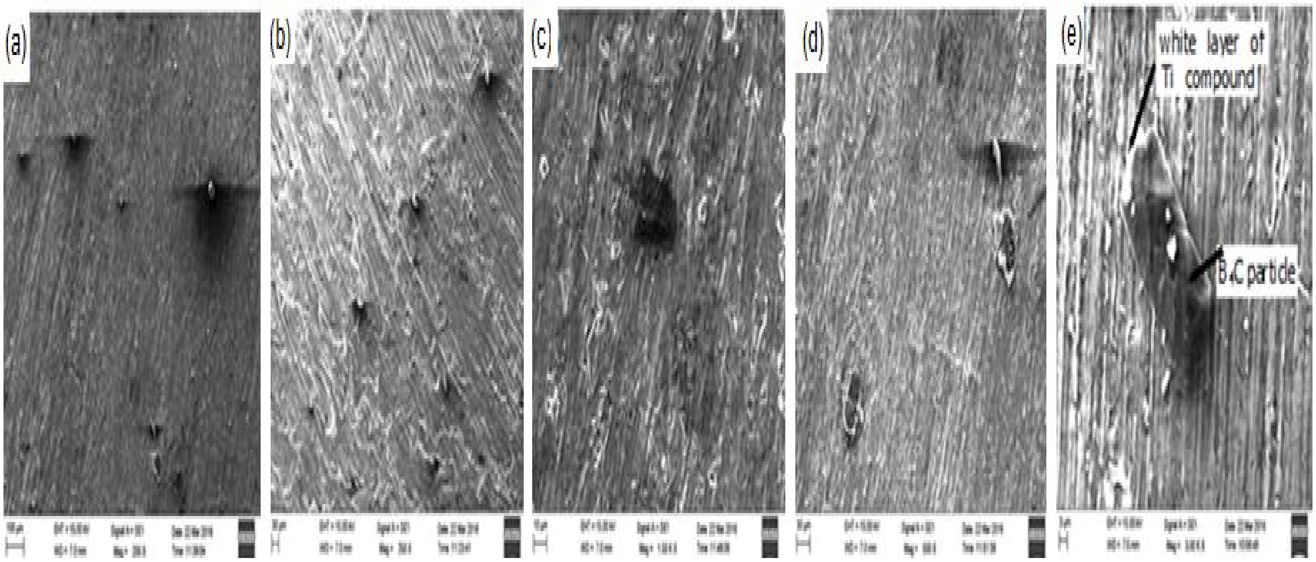

Fig. 1 AA6061 reinforced with (a) 0% (b) 1% (c) 2% (d) 3% (e) 4%wt% B_4C particulates

B. Wear characteristics

1) Effect of Load on Specific Wear Rate: Fig. 2, 3, 4 and 5, shows the variation of specific wear rate under different load condition at Constant speed of 200 rpm, Track diameter of 90 mm and Time 5 min. The variation of specific wear rate against load at 10N, 20N, 30N, 40N and 50N for unreinforced alloy and four different composite specimens with varying volume percentage particle reinforcement (0, 1, 2, 3 and 4% of B_4C). From the test, it shows that specific wear rate decreases as the load increases at all temperature range and its wear is high for as-cast at 10 N and low for 4% AA6061+B_4C at 50 N. In case of as-cast pressure exerted on the specimen tip causes severe plastic deformation resulting in material removal at faster rate. But due to presence of hard ceramic reinforcement B_4C in Al matrix, it reduces the direct metal to metal contact leading to less wear and also formation of glaze that offers a protection and avoids further wear.

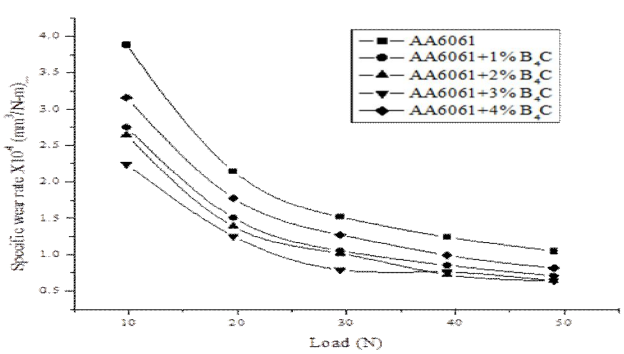

Fig. 2 Load v/s Specific wear rate at room temperature (26 ºC)

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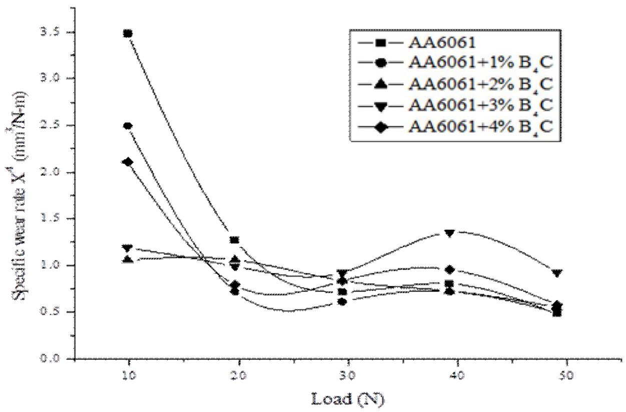

Fig. 3 Load v/s specific wear rate at higher temperature at 50 ºC

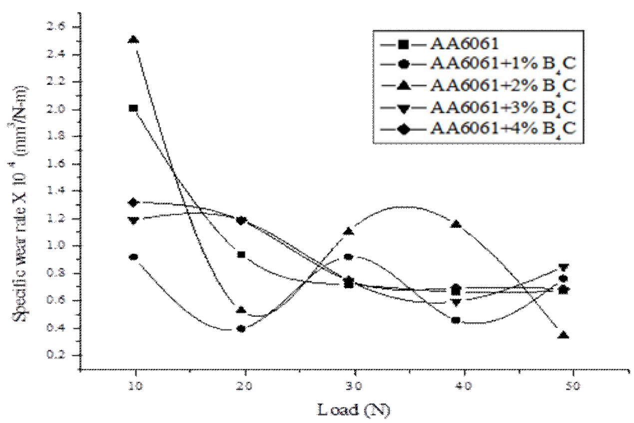

Fig. 4 Load v/s specific wear rate at higher temperature at 100 ºC

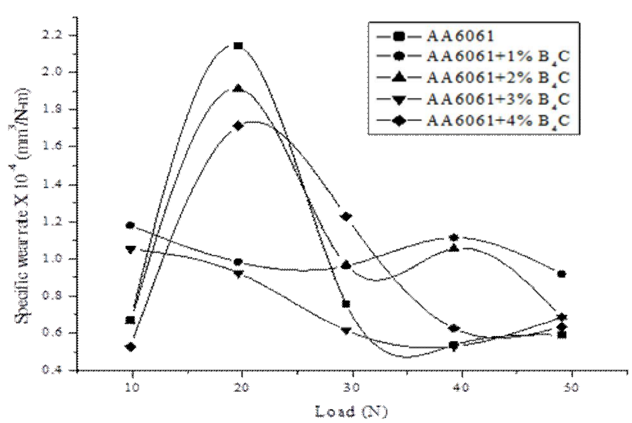

Fig. 5 Load v/s Specific wear rate at higher temperature at 150 ºC

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2) Effect of Temperature on Wear Rate: Figure 6, 7, 8, 9 and 10, shows the variation of wear rate at different temperature under different load condition 10N, 20N, 30N, 40N and 50N at constant speed of 200 rpm, track diameter of 90 mm and time 5 min for unreinforced alloy and four different composite specimens with varying volume percentage particle reinforcement (0, 1, 2, 3 and 4% of B_4C). The effect of temperature on wear rate of AA6061 alloy under different temperature with different load, From the figures, it is clear that wear rate of AA6061 alloy without reinforcement increases with increasing temperature and load from mild to severe conditions, whereas for AA6061 alloy with reinforcement, oxide layers were observed to be formed, due to which the wear rate increases up to temperature (50 to 100 ºC) with increase in load, and thereafter it decreases at 150 ºC temperature for all the composition is due to the reason that the pin protects the wear surface due to formation of oxide layer.

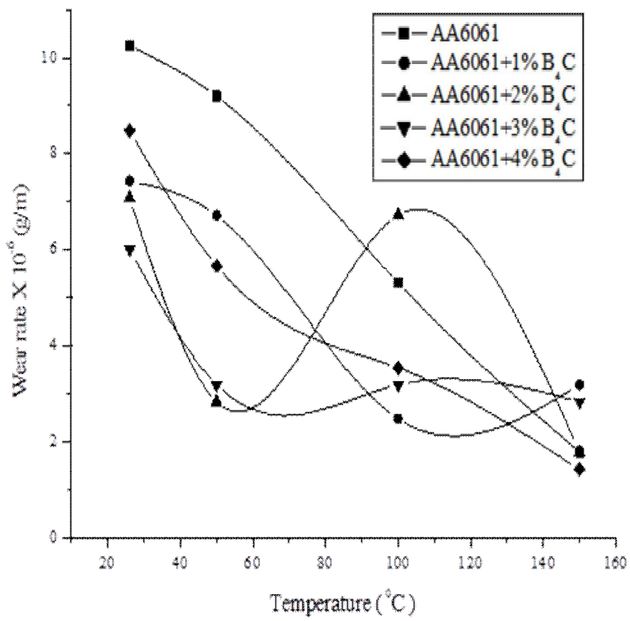

Fig. 6 Temperature v/s Wear rate at Load 9.81 N

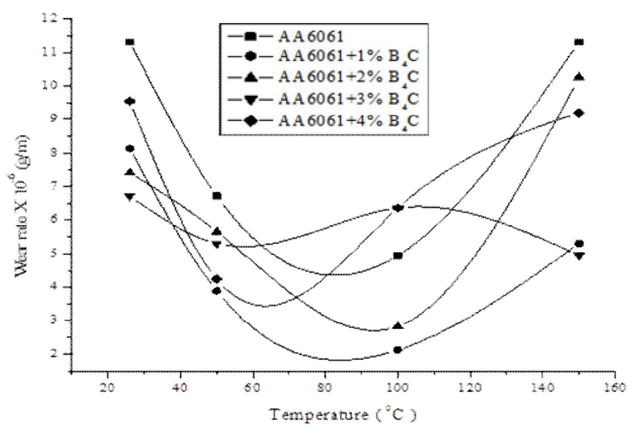

Fig. 7 Temperature v/s Wear rate at Load at 19.62 N

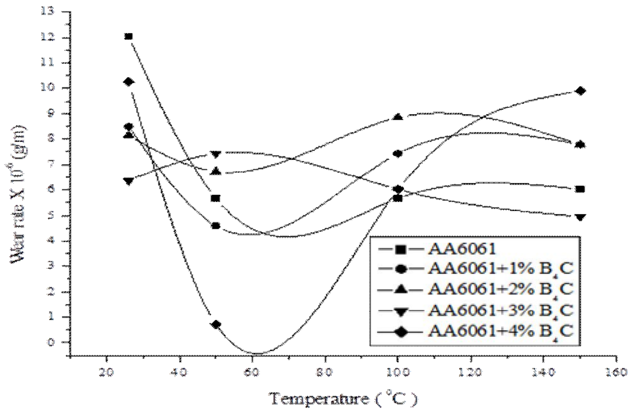

Fig. 8 Temperature v/s Wear rate at Load at 29.43 N

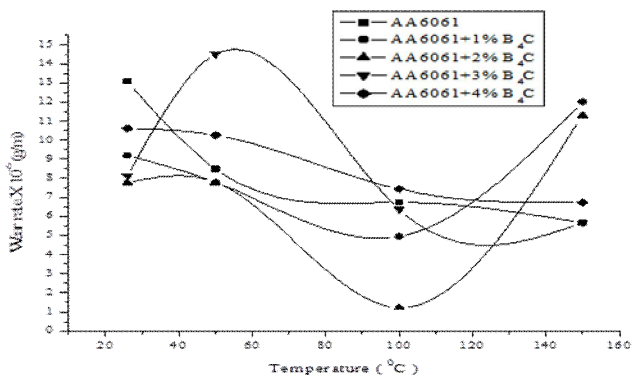

Fig. 9 Temperature v/s Wear rate at Load at 39.24 N

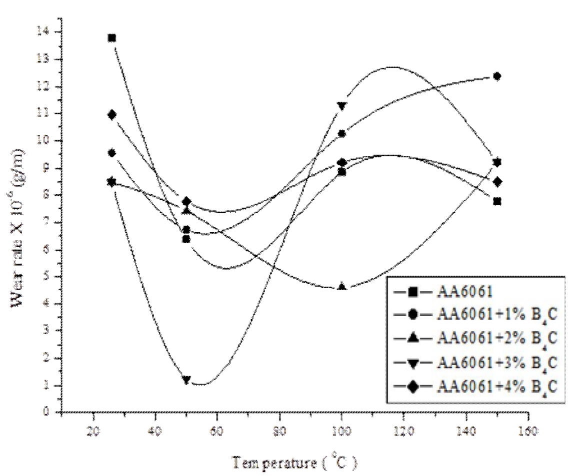

Fig. 10 Temperature v/s Wear rate at Load at 49.05 N

C. Worn Surface Studies

SEM micrographs of worn surface of un-reinforced AA6061 and worn surface of AA6061+ 4% B_4C composites at a sliding speed of 0.94 m/s at normal load of 49.05 N are shown in the figure 11 and 12. Due to plastic deformation unreinforced alloy shows severe wear as compared to reinforced condition. Formation of groves are clearly visible with smaller groves indicating abrasive wear.

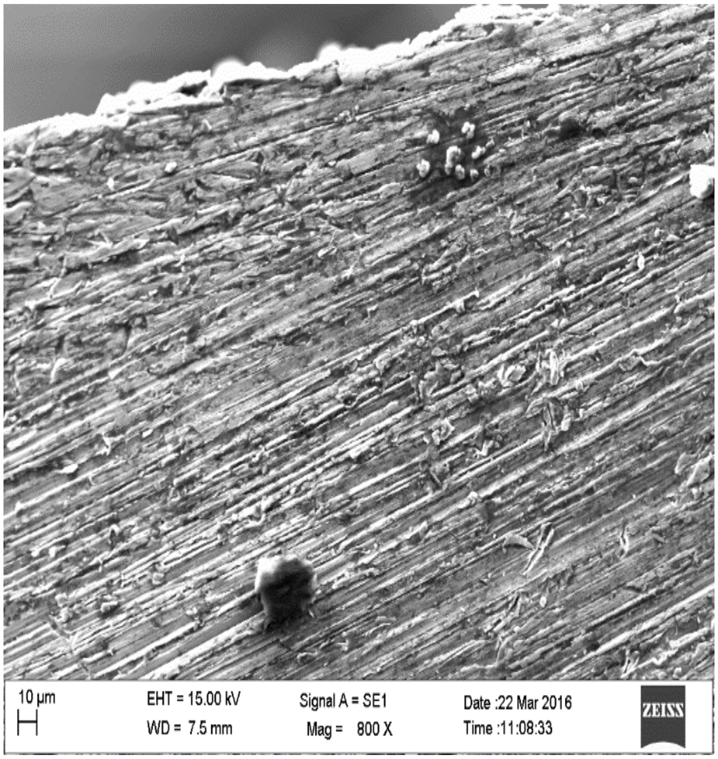

Fig. 11 Worn surface image of unreinforced AA6061

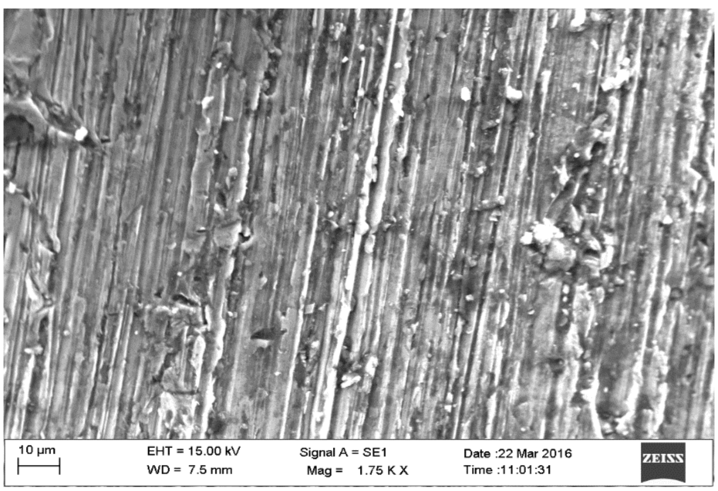

Fig. 12 Worn surface image of AA6061-4% B_4C

IV. CONCLUSIONS

The tribological behavior of different percentage of B_4C particulates in AA6061 matrix composite at room and elevated temperatures. Wear and metallographic examination were performed and following results were obtained. The SEM images reveal that the homogeneous distribution of B_4C particles in the aluminium matrix for all wt. %. Wear properties are considerably improved by the addition of hard ceramic particles and wear resistance of these reinforced alloys is also higher than that of base alloy for all operating temperature conditions. The wear rate of prepared composites decreases with an increase in temperature with a constant sliding distance. This effect is due to oxide film formation on sliding components, which is more rapid at high operating temperatures. The later prevent direct metal to metal contact of sliding surface. It is also observed that wear rate is less than that of AA6061 base alloy. Worn surface showed small to medium size grooves, it can be concluded that load is the main factor for wear rate.

V. ACKNOWLEDGEMENTS

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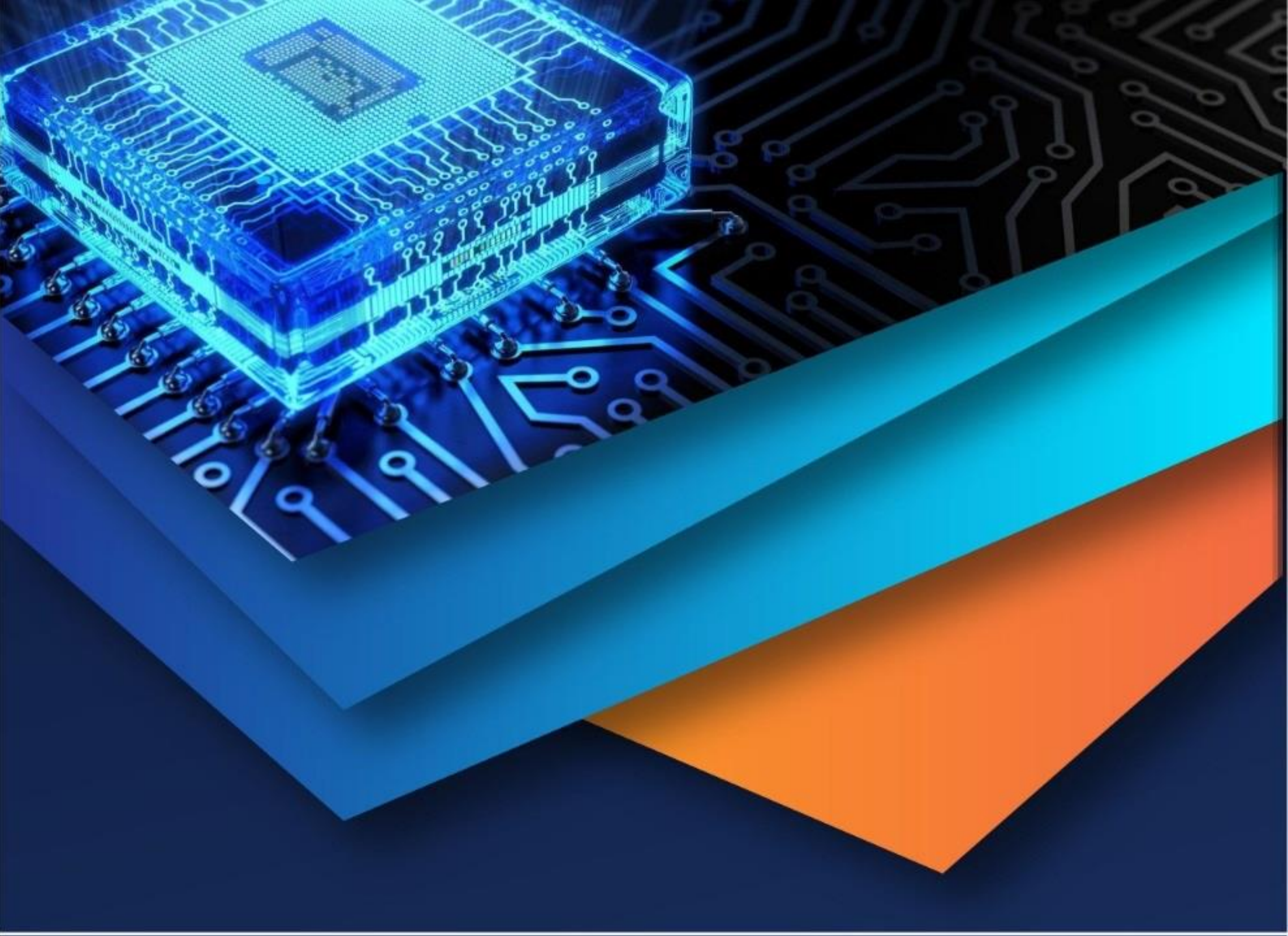

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